(12) UK Patent Application (19) GB (11) 2 083 966 A

(21) Application No 8127941
(22) Date of filing 16 Sep 1981
(30) Priority data
(31) 8030085
(32) 17 Sep 1980
(33) United Kingdon (GB)
(43) Application published 31 Mar 1982
(51) INT CL³ G01S 7/40
(52) Domestic classification H4D 234 23X 382 38X
(56) Documents cited GB 1589047 FR 2392396 A
(58) Field of search H4D
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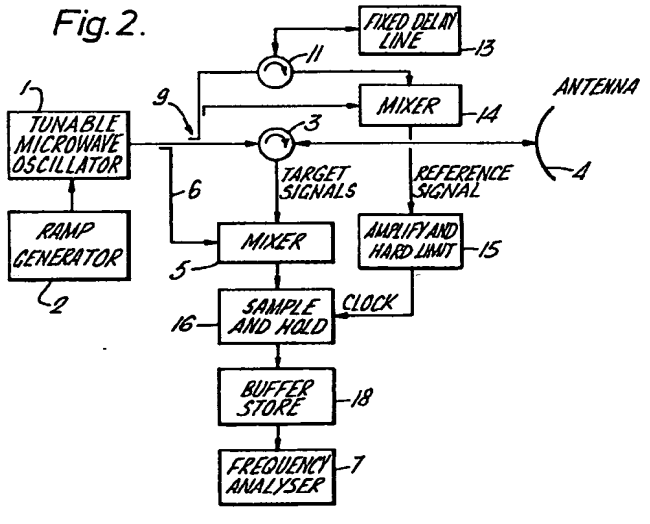
(54) Frequency-modulation radar

(57) In an FMCW radar ranging system, the modulation being of ramp form so that the return signal should exhibit a constant frequency difference dependent on the range delay, lack of linearity of the transmitted signal ramp causes false difference frequencies to arise which reduce ranging certainty. This is overcome by obtaining a target difference frequency signal as before and deriving a reference difference signal by feeding a portion of the transmitted signal into a fixed delay 13 and mixing 14 as for a target. The reference difference signal also, therefore, suffers from ramp non-linearities. A sampling signal of correspondingly irregular repetition rate is picked off 15 this reference difference signal and used to sample the target difference signal. The samples are therefore non-linearly distributed in time in a way which offsets the non-linearity of the transmitted frequency ramp. By treating the samples as though they were equally spaced in time, conventional narrowband frequency analysis can be used to derive the target ranges.

Fig. 2.



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SPECIFICATION

Radar ranging system

This invention relates to frequency modulated continuous wave (FMCW) ranging systems.

Radar ranging systems commonly employ a frequency modulated continuous wave (FMCW) transmitted signal as an alternative to a pulse system to provide a time marker on the transmitted wave. If the transmitted signal is a microwave frequency swept through a predetermined range repeatedly and linearly, the frequency difference between the transmitted signal and the signal reflected from a target (the radar 'returns') is a measure of the time lapse of the reflected signal and thus of the target range. Thus Figures 1(a) and 1(b) illustrate the basic FMCW Radar in which r.f. transmissions are radiated from an antenna, reflected from an object at a distance d metres, and return to the radar after a time $\Delta t = 2d/c$ where c is the velocity of light. The transmitted frequency is made to increase linearly with time so that there is a difference Δf between the transmitted frequency and the frequency of reflected signals. Δf is proportional to the time delay Δt of the reflected signals and to the rate of change of transmitted frequency $\frac{df}{dt}$

In order to measure the range, d, it is therefore necessary to measure the difference frequency Δf and to know the rate of change of transmitted frequency df/dt. Various methods have been published for controlling df/dt, one such method being described in US Patent Specification 4106020. The method there described corrects the measured value of range by detecting the difference frequency and counting the number of cycles over a period chosen to scale the count appropriately.

There are, however, many difficult applications where the return signals are weak compared with system noise, and multiple returns are present. High resolution filtering is therefore necessary to achieve a good signal to noise ratio and to resolve components from different ranges before the wanted signal can be detected. If this filtering is carried out by a narrowband filter, there is a limitation on the improvement available due to non-linearity in the transmitted tuning characteristic. Changes in df/dt cause the difference frequency to change, and so the returns from a fixed range will cover a band of frequencies, with a corresponding loss in output signal/noise ratio from a narrowband filter. A method of compensation is therefore required which is applicable before the signals are detected and which therefore enables high resolution filtering at the output.

According to the present invention, in a radar ranging system comprising a swept-frequency transmitter, a difference-frequency circuit providing a target difference-frequency signal of frequency equal to the difference between the transmitted and reflected signals, a sampling circuit for sampling the target difference-frequency signal and processing circuitry for deriving the target range from the values of the samples and their repetition frequency, a reference difference-signal is provided by the transmitted signal and a version thereof time displaced by a predetermined period, the sampling of the target difference-frequency signal being performed at the reference difference-frequency to avoid the effect of a non-linear frequency sweep.

The system may include means for producing an intermediate frequency (I.F.) signal from the outputs of the swept-frequency transmitter and a microwave local oscillator, and a delay line to which the I.F. signal is applied, the resulting delayed I.F. signal being differenced with the undelayed I.F. signal to produce the sampling signal.

Several embodiments of a radar ranging system in accordance with the invention, will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 shows a block diagram and associated frequency modulation diagram of a conventional FMCW radar system;

Figure 2 shows a block diagram of a basic radar system according to the invention; and

Figure 3 shows a modification of the system of Figure 2.

The basic system of Figure 1 has already been referred to. It incorporates a voltage tunable microwave oscillator 1, which is swept in frequency by the output of a ramp generator 2. The oscillator output is then applied to a circulator 3 having an output port connected to a transmitting and receiving antenna 4. The radar returns are received by the antenna and fed back to the circulator 3 which passes them on to a receiver including a mixer 5. The transmitted signal from the oscillator 1 normally achieves some leakage from the input port of the circulator 3 to the output port feeding the mixer 5. The leakage portion of the transmitted signal and the reflected signal are mixed in the receiver 5 and a difference frequency signal produced. This leakage is indicated by a path 6.

As explained above, the frequency of this difference signal will depend upon the sweep rate of the transmitted signal and the time lapse between transmission and reception of the reflected signal. If the sweep rate is constant the difference frequency is proportional to the target range. If, however, as is commonly the case, the sweep rate is not constant, the difference frequency will vary throughout the sweep and will therefore not be a good indication of range.

A frequency analyser 7 is employed to measure the difference frequency, since in practice there will generally be returns from a number of different targets and hence the output of the differencing circuits will comprise a number of sine waves of different frequencies. The analyser samples the input signal at a predetermined sampling frequency, quantises the analogue samples and performs a

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

digital analysis to determine the frequency of the signal (if a single frequency) or the frequencies of the components, if derived from a multi-target situation.

Clearly, a non-linear sweep will, since it produces frequency modulation, cause the analyser to indicate the presence of multiple targets when in fact there is only one present.

Figure 2 shows a basic embodiment of an FMCW radar incorporating the invention. The same arrangement of oscillator 1, ramp generator 2, circulator 3, antenna 4 and mixer 5 is employed as before. In addition however, to the production of the target difference-frequency signal, by way of the antenna 4 and circulator 3, a reference difference-frequency signal is produced by way of a coupler 9, a circulator 11 and a fixed delay circuit 13.

A portion of the transmitted signal is passed by the coupler 9 to the delay circuit 13 by way of the circulator 11. On reflection to the circulator 11, the delayed signal is applied to a mixer circuit 14 together with a 'leaked' portion of transmitted signal, as for the main mixer 5. The resulting reference difference signal is applied to a detector circuit 15.

The reference signal has a frequency which, in the same way as for the target difference signal, is dependent upon the sweep rate and the 'range' which is simulated by the delay 13. Since this delay is constant, the reference frequency varies solely in dependence upon the rate of change of frequency of the sweep signal.

On application to the circuit 15, the reference signal is detected, amplified and limited, to produce a 'square' waveform, the transitions of which provide sampling pulses in known manner. The repetition rate of these sampling pulses will then vary in exact correspondence with any departure from linearity of the sweep rate.

The target difference signal is derived by the circulator 3 and mixer 5, and applied to a sample-and-hold circuit 16 which produces an analogue sample at the instant of each sampling pulse from the circuit 15. The sample-and-hold circuit also includes an analogue/digital converter which quantises the analogue samples to produce a series of digital sample values.

Assuming the sweep rate is non-linear these digital samples will arise at a rate which may, for example, increase throughout each sweep. This variation is, however, ignored by supplying them to a buffer store 18 at whatever rate they arise. They are then processed simply as a series of samples of constant time spacing and are analysed accordingly by a frequency analyser 7 to determine the apparent frequencies of the component or components, which are now directly related to target ranges.

The constant sample rate assumed by the analyser 7 in determining the frequency from the sample values may be the average value of the actual sampling rate or may be an arbitrary value which would have the effect of scaling the target difference frequency.

It may be seen that by means of the invention, if the target difference frequency increases throughout the sweep (without any change in target range) the sampling frequency is increased correspondingly so that samples are taken at the same point on the waveform (and thus have the same value) as if the difference frequency had been constant.

It has been assumed above that the delay imposed on the reference signal, although fixed, is arbitrary. This is not so because analysis of a set of samples to determine the waveform(s) from which they arose requires that the samples occur at at least twice the frequency of the highest frequency component. In this case the highest frequency component will arise from the most distant target, i.e. from the upper limit of the range of targets that the system accommodates. Consequently, the reference difference frequency, i.e. the sampling frequency must be obtained from a delay (13) which is at least twice the time lapse corresponding to the upper limit of the target range.

In practice, it is not easy to obtain a significant delay with a mocrowave signal and one way of overcoming the difficulty is the arrangement of Figure 3. In this arrangement a portion of the swept signal is applied to a mixer 20 which also receives a microwave local oscillator (19) signal of fixed frequency. Thus the whole of the swept signal is shifted to a relatively low frequency band. This intermediate frequency (I.F.) signal is applied to a circulator 11 which passes it to a delay line 13. A significant delay is easily achieved at the low frequency and the reflected signal is mixed with the incident signal in the mixer 14 to provide the same reference difference signal for sampling as before.

In a further alternative, the delay 13 in Figure 2 is accepted at a low value easily achieved at the microwave frequency. The reference difference signal resulting is consequently of too low a frequency but is multiplied up in a phase lock loop by phase comparison with the divided output of a voltage controlled oscillator. The oscillator output itself then provides the reference signal of suitably high frequency.

The term 'target' has been used in this specification to denote the reflecting object but this does not of course necessarily imply any military significance. In fact a prime application of the invention is in the determination of the topography of a coal mine and the control of automated mining operations.

It will be seen that the invention provides an FMCW ranging system in which compensation for non-linearities in the frequency modulation rate is achieved. The method of compensation remains effective in the presence of multiple returns and also when the signal to noise ratio is low.

CLAIMS

1. A radar ranging system comprising a swept-frequency transmitter (1), a difference-frequency circuit (3) providing a target difference-frequency signal of frequency equal to the difference between the transmitted and reflected signals, a sampling circuit (16) for sampling the target difference-frequency signal and processing circuitry (7) for deriving the target range from the values of the samples and their repetition frequency, wherein a reference difference-frequency signal is provided (9, 11, 13, 14, 15) by the transmitted signal and a version thereof time displaced by a predetermined period, the sampling of the target difference-frequency signal being

performed at the reference difference-frequency to avoid the effect of a non-linear frequency sweep.

2. A radar ranging system according to Claim 1, including means (20) for producing an intermediate frequency (I.F.) signal from the outputs of the swept-frequency transmitter (1) and a microwave local oscillator (19), a delay line (13) to which the I.F. signal is applied, the resulting delayed I.F. signal being differenced (14) with the un-delayed I.F. signal to produce the sampling signal.

3. A radar ranging system according to Claim 1, wherein said reference difference-frequency signal is provided by multiplication of the frequency of a first signal derived by differencing the transmitted signal with a time-displaced version thereof, the necessary time displacement being then reduced in inverse proportion to the multiplication factor.

4. A radar ranging system according to Claim 3, wherein said multiplication is effected by a phase-locked loop having a controlled frequency input which is divided down to provide a signal the frequency of which is compared with that of said first signal to control said frequency input.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1982.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

Fig. 1(a)

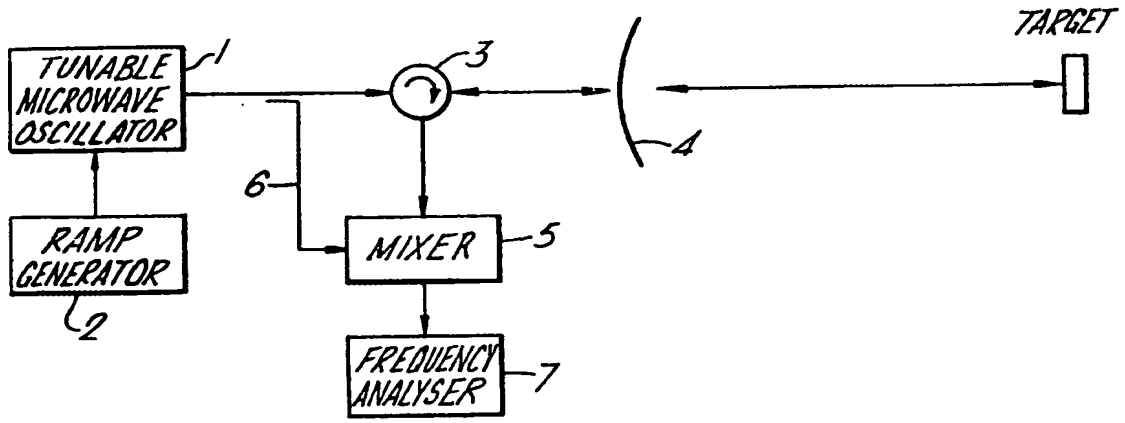

TUNABLE MICROWAVE OSCILLATOR
1
3
TARGET
4
6
RAMP GENERATOR
2
MIXER
5
FREQUENCY ANALYSER
7

Fig. 1(b)

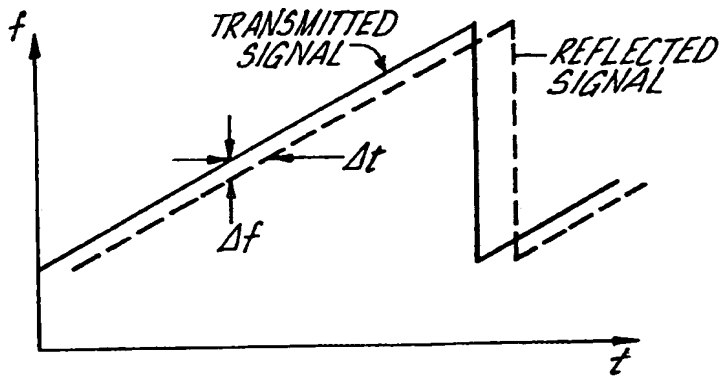

f
TRANSMITTED SIGNAL
REFLECTED SIGNAL
Δt
Δf
t

Fig. 2.

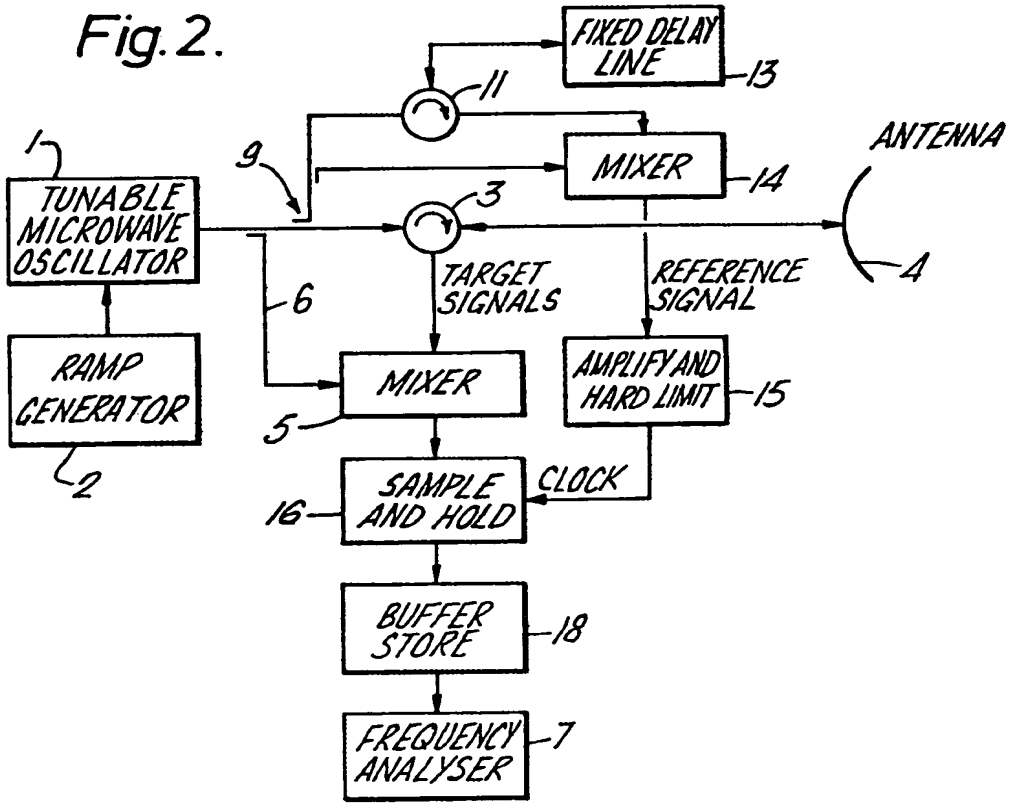
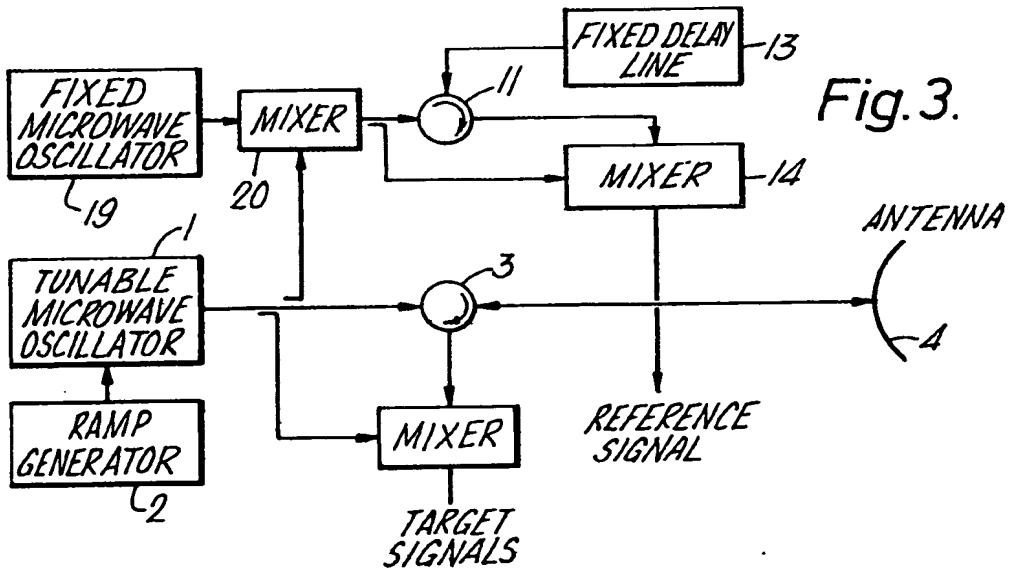

FIXED DELAY LINE
13
11
ANTENNA
1
9
MIXER
14
TUNABLE MICROWAVE OSCILLATOR
3
4
6
TARGET SIGNALS
REFERENCE SIGNAL
RAMP GENERATOR
MIXER
AMPLIFY AND HARD LIMIT
15
2
5
CLOCK
SAMPLE AND HOLD
16
BUFFER STORE
18
FREQUENCY ANALYSER
7

Fig. 3.


FIXED DELAY LINE
13
FIXED MICROWAVE OSCILLATOR
MIXER
11
MIXER
14
19
20
ANTENNA
1
TUNABLE MICROWAVE OSCILLATOR
3
4
RAMP GENERATOR
MIXER
REFERENCE SIGNAL
2
TARGET SIGNALS